BASIC GUIDE TO CORROSION PROTECTION

FOR

MIAMI-DADE WATER AND SEWER DEPARTMENT PROJECTS

CORROSION PROTECTION

INTRODUCTION:

Purpose:

A large volume of material has been generated in various engineering and scientific publications on the subject of corrosion protection and prevention in sanitary sewer systems. Much of said material involves extensive testing of such things as sewer content, pipe wall acidity and soil resistivity. This is further combined with extensive calculations of gas generation potential, flow modeling and station wet well design. This works well when the design professional has a large project or series of projects which permit the time and overhead investment required for such work. On the other hand, the design for a small collection system, pump station and force main for a client may not permit this kind of investment of time and manpower.

The information contained herein is presented for the latter type of situation and is to be considered as a basic guide to corrosion protection for departmental project work. Most of the guidelines presented here are specific to this department and have been developed over the years in response to situations occurring in our own system of sewers. Thus, our particular solutions may well vary from those used in other areas of the country.

Two further considerations have bearing on the material presented here. First, this department has always had the philosophy that it was best to utilize and require the best materials for construction of our facilities. This is done deliberately with the view to saving the future cost of system failures, repairs and replacement. Even so we have learned some hard and expensive lessons on what does and does not work.

Second, the department has always tried, where and when possible, to utilize materials, methods and systems that are well proven. This with the recognition that when we open the door to a material or process, it may well be that a failure will not show up for several years. Thus, we can be confronted with a situation where a large amount of material is already installed when a failure mode becomes apparent. Such a situation is very costly and creates great public inconvenience.

Background:

In the early 1980's the department became aware through TV direct visual inspections that extensive internal corrosion had and was taking place in the gravity interceptor systems installed in the early 1950's. These sewers were state of the art at the time of their construction but were unlined reinforced concrete cylinder pipe. On the first interceptor scheduled for repair, it was found that the 42-inch diameter cylinder pipe with 5-inch thick wall installed some thirty-three years before, had been corroded to a point where no reinforcing and only one inch of concrete remained in portions of the crown of the pipe.

In October of 1987, a sudden increase in flow into Pump Station No. 1, on the Miami River resulted in the discovery that a failure had occurred in the 42-inch syphon pipe feeding this station from the south.

Subsequent to this time several failures were experienced over a period of years in the 54-inch force main transmitting sewage from the western areas of the county to the Central District Treatment Plant.

All of these failures were due to internal pipeline corrosion caused by sewer gas attack of the concrete pipe walls. This is the most pervasive form of corrosion failure experienced in our system.

This type of attack is caused when the BOD (biological oxygen demand) of the organic material in the sewage flow is such as to use up all or nearly all of the oxygen in the liquid. At that point, anaerobic bacteria become prevalent and through their activities generate hydrogen sulfide gas. Our system which due to the nature of our terrain, has flat slopes with relatively long sewage residence times combined with high temperatures all year provide near excellent conditions for this type of situation to develop. This type of occurrence is almost unavoidable and generally speaking, the further downstream in position or time of a given site, the more likely is a corrosive environment.

The hydrogen sulfide gas produced will directly corrode metals such as electrical contacts and other materials made of iron, steel and copper. Further, in the presence of air and water vapor, certain bacteria of the genus Thiobacillus[1] will oxidize the gas to sulfuric acid which results in extensive corrosion of concrete sewer main walls. This has been the major cause of pipeline failures and deterioration in Dade County and other parts of the country.

The Pomeroy-Parkhurst equation[2] can be used to estimate the amount of hydrogen sulfide which will be generated in a sewer pipeline. However, in some instances field results can vary as much as fifty percent above and below results of the equations.[3] Thus, calculated results should be confirmed by field tests or used as a good estimate rather than absolutes.

In this county, we have had relatively little failure of sewage mains or structures due to external corrosion. The only instances of corrosion problems of this sort known to the author are the failure of an area of 20-inch ductile iron force main at Pump Station No. 301 near Sunny Isles and some corrosion problems associated with bridge mounted force mains entering salt water areas at channel crossings.

The extensive corrosion of the 20-inch main at Station 301 is believed to have been caused by stray electrical currents possibly due to some power cables in the area. This type of situation has not been commonly encountered and many mains are located near such power sources. Thus, this failure is not entirely explained at present.

The other corrosion instance is normal enough and fortunately a not very extensive problem. Ductile iron when put into a situation where it is constantly exposed to alternate wet-dry conditions due to tide and wave action will corrode relatively rapidly. Thus, such a situation is to be avoided where possible.

PUMP STATION DESIGN

Design Considerations

The design engineer should look at several aspects of the individual project to asses the corrosion potential of the particular situation.

The first consideration should be an assessment of whether or not the sewage flow will likely be aerobic or anaerobic at any portion of the system in question. Areas where protection should always be considered as required are the pump station wet well and the force main piping. This is particularly the case in any instance, such as a force main emptying into a wet well or manhole, where there is a good possibility of an anaerobic condition being present in the flow.

Three other instances where anaerobic conditions should be anticipated are: (1) where high concentrations of organics are entering a system such as near a food processing facility; (2) where sewage residence time is extended, such as a pump station handling a low flow situation where wet well residence times are relatively long and (3) where the sewage flow has already had a long residence in the system such as at a major pumping station which takes in flow from a wide area.

Turbulence and solids deposition should be minimized to discourage the release of gasses. At present the concerned divisions within the department are evaluating the use of a steeply sloped intake pipe or drop connection inlet combined with a restricted, sharply sloped wet well floor configuration to reduce turbulence and reduce solids/scum build up.[4] If these changes to the standard configuration are found to be beneficial and not cause maintenance or other related problems they will be incorporated in future design updates.

Fan powered ventilation of both the wet and dry wells when occupied is required and is dealt with elsewhere in the design requirements. Further, ventilation of the wet well via the standard gooseneck, if out of the right of way and via a pipe brought above grade adjacent to the control panel if in the right of way is also a design requirement.

Fan ventilation for the purpose of corrosion protection is always desirable and the wet well should, where feasible, be provided with an intake fan as shown in the standard drawings for wet well/dry well installations. Feasibility depends on two considerations: (1) whether the wet well location is out of the right of way and there is no danger of a vehicle running over the fan installation; (2) whether the exhaust from the wet well can be vented in a location where any odors will not create objectionable conditions for area residents. Given these two requirements, the fan can be wired to run continuously when the wet well hatch is opened (occupied condition) and either continuously or on a timed basis when not occupied at the option of the department. Fan motor under all conditions shall be of a continuous duty type.

<u>Structural Materials</u>

Aluminum: Structural shapes, sheets, plates, bars and pipe; Alloy 6061-T6. Pipe schedule 80 minimum. Flattened expanded aluminum mesh Alloy 3003-H14. All aluminum except for conduit shall be anodized: sheet AA-M10C11C21A31, min.0.4 mil coating; Structural shapes, plates bars and pipe, AA-M10C11C21A41, min. 0.8 mil coating. See electrical specifications for conduit.

Bronze: Conform with ASTM Standards B61, "Steam or Valve Bronze Castings"; B62, "Composition Bronze or Ounce Metal Castings"; B139, "Phosphor Bronze Rod, Bar, and Shapes", Grade A,C or D; B584, "Copper Alloy Sand Casting for General Applications", Copper Alloy C84400.

Brass: Not permitted in any corrosive environment.

Copper: See elsewhere herein under pipeline materials.

Cast, Ductile Iron:
Grey Iron Castings, ASTM A48, Class 30 iron, manufacturer's identification and country of origin to be cast in to product. Note that a fabricator shall <u>not</u>

be considered a manufacturer for the purpose of identification of producer.

Ductile Iron Castings, ASTM A536, Grade 65-45-12, identification of manufacturer as above unless otherwise specifically permitted by the Department for machined elements only.

Unless otherwise specifically required by the Department for a particular type of item, all items shall be supplied without coating to facilitate visual examination upon receipt of shipment.

Cast, Ductile Iron pipe is specified elsewhere herein.

Concrete: For all sanitary applications utilize ASTM C150, type II, cement only. Protect from corrosive attack with lining or coating as specified below.

Fiberglass and Plastics:
See pipeline materials below.

Steel, Carbon:
Grade as specified for the individual application. Unless otherwise specified, always to be hot dip galvanized per ASTM A123, "Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products; or ASTM A153, "Zinc Coating (Hot-Dip) on Iron and Steel Hardware".

Steel, Stainless:
Unless otherwise specifically permitted by the Department, always to be AISI Type 316 (non-welded)or 316L (for welded applications).Material requiring hardening shall be AISI Series 400 stainless steels.

<u>Lining and Coating Materials</u>

This is a very large and rapidly developing area of materials. The list included herein is not inclusive but rather indicative. The design professional should, at design inception, check with the Department for up to date information regarding what is at that time being accepted for the particular application.

Where required by the Department, all surfaces of the wet well or manholes above the bench shall be protected from corrosion with a WASD approved lining system or coating. Check at the beginning of design for requirements.

Mechanical Lock Plastic Lining:

CORROSION PROTECTION

When lining is required, the entire upper portion of the interior wet well surface except for the hatch shall be completely sealed and protected with plastic lining. The lining shall be Amer-Plate T-Lock Liner Plate as manufactured by Amercoat Corporation, Brea, California, or Lok-Rib Koroseal Concrete Pipe Lining as manufactured by B.F. Goodrich General Products Company, Akron, Ohio, or approved equal. As used herein, the word "pipe" shall also mean "fitting" or "special".

All interior surfaces except for the bench shall be lined. Particular care shall be exercised to line all areas where pipe enter or leave the structure so as to not leave any opening or edge where the structure is exposed to attack. In areas where it is impossible to utilize T-shaped ribs and a smooth liner must be used, the liner shall be attached to the wall by adhesive and 316 stainless steel studs into the structure wall at maximum 9-inch intervals C.C.E.W. At each stud location an additional two inch square (minimum) of liner shall be adhered to the liner before the stud is put through the material. This to provide a double thickness of material under the head of each stud. Each stud shall be provided with a minimum 1-inch diameter washer of either Department approved hard plastic or 316 stainless steel. Note that 1-inch by 1/4-inch thick plastic strips may be utilized in place of the washers if approved by the Department. Note that the Department reserves the right to require 316 washers and in that instance the Engineer's word shall be final. The head of each stud shall be covered by an adhesive attached liner patch or in the case of strip reinforcement by a strip of material.

All lining material furnished shall consist of a PVC compound which has been used in comparative service, and formed under pressure into permanently flexible sheets not less than 0.065-inch in thickness and which shall withstand a 40 psi back pressure. Except where otherwise required, it shall be provided with integrally molded T-shaped longitudinal ribs which, when embedded in the concrete, will securely and adequately anchor the lining in place.

All outlets and connections within the designated limits of the plastic lining shall be completely sealed and protected with the plastic lining. As previously specified, lining shall be carried over to an extent that no structure material shall be exposed to corrosive attack. Joints shall be kept at a minimum. Except where outlets are required, the plastic lining shall as near as possible consist of a single sheet of material. Where joints occur between individual sheets or sections of lining, they shall be continuously heat-welded, either by lapping adjacent sheets or with the use of auxiliary welding strips cut from the same kind and thickness of material as the liner plates (with the exception of the T-lock ribs). At outlets the lining shall be turned back into the joint or otherwise suitably terminated so that the edges are adequately protected and anchored.

The liner shall extend to the end of the interior concrete surface at both the top slab and bench of the wet well. A minimum 4-inch wide liner strip shall be provided for each liner joint which must be field assembled such as between the top slab and walls. This strip shall have no integral ribs and shall be welded over both sides of the field joint so as to overlap both liner ends at the joints by a minimum of one inch. Joint strips shall be made of the same material and thickness as the structure liner plates.

All adhesive welding materials and separate strips of lining material for field joints shall be furnished by the lining material manufacturer.

All work in connection with the installation of the plastic lining in the structure shall be performed in strict conformity with the lining manufacturer's recommendations. Liner sheets shall be fastened in place securely in the forms before reinforcing steel or concrete is placed.

Care shall be taken in handling and transporting plastic-lined precast structures to prevent damage to the liner. No interior hooks or other interior lifting device shall be used in handling the precast unit; all handling requiring lifting or suspension shall be done by using exterior slings or cast-in lifting points. No structure with damaged lining will be accepted for installation until and unless the damage has been repaired to the satisfaction of the Engineer.

The manufacturer shall furnish data certifying that the lining is of the material specified. All liner material and shop welds shall be tested by the liner manufacturer at the manufacturer's plant with an approved, properly calibrated, fully charged, electrical hole detector set at 20,000 volts. Sheets having holes shall be properly repaired in the shop prior to shipment from the manufacturer's plant. Repairs shall be made only by qualified welders. The manufacturer shall provide certification that all lining material supplied has passed these tests. No lined structure will be accepted until certificates have been submitted and approved by the Engineer.

At this point it would be well to note the following facts in relation to corrosion protective lining systems.

1. Recently two new mechanically attached lining systems have been mentioned to the Department. These are the AGRU Sure-Grip High Density Polyethylene (HDPE) liner and the Sure-Grip Polypropylene random copolymer (PP-R)

liner. To date the author has no knowledge of these linings being utilized by the Department and thus, they are as yet unapproved. This is not meant to imply anything about the future use or non use of these products.

2. Some literature has suggested the use of rubber boots for pipe entrance and exit from manholes and other underground structures. These units are not utilized or approved by the Department. Pipe is not to be connected by boots.

3. Some literature has advanced the idea of using smaller diameter structures with thinner walls having a cast in liner. This is not acceptable to the Department. Minimum manhole diameter is 48 inches or greater if required and minimum wall thickness is eight inches or greater if so required by design.

Co-Lining System:

Materials:

The co-lining system shall consist of four materials: an epoxy/urethane primer, a high solids polyurethane mastic/joint sealant, a surface activator, and an extruded polyvinyl chloride sheet as manufactured or supplied by Linabond, Inc., Los Angeles, California, telephone number (213) 650-6077. Materials list for the protective co-lining system shall be submitted and shall include certification from a certified laboratory that the materials meet the following specifications. No substitutes for these materials will be allowed.

1. The epoxy/urethane primer shall be two component fast cure primer with high tolerance for moisture which strongly bond to the concrete and the polyurethane mastic. The intended use and properties of the primer is as follows:

   a. Linabond Primer EP30 - Primer with faster cure rate to be used where range conditions of higher moisture content and colder temperature are present.

Mix Ratio	=	1:1
Elongation	=	35%
Tensile Strength	=	> 2,800 psi
Weight/gallon	=	9.6 lbs
Solids	=	23%
Viscosity	=	250 centipoise
Pot Life	=	8 hours

The primer shall approved by Linabond, and supplied by Linabond Inc.

2. The polyurethane mastic shall be a high solids polyurethane mastic/joint sealant. The mastic shall be permanently flexible, non-flow, and shall be resistant to weathering, aging, dilute acids (10 percent sulfuric acid solution, or acid conditions generating pH levels of 1.0) and dilute alkalis. The material shall exhibit excellent adhesion to the activated polyvinyl chloride liner and to the primed concrete surface. It shall exhibit the following properties:

Performance Properties	=	Non-flow(typical)
Hardness, Shore A	=	> 30
Non-volatile Content	=	> 93%
Adhesion, ASTM C920	=	> 23 ply
Tensile, ASTM D412	=	> 175 psi
Elongation, ASTM D1412	=	> 300%
Maximum Usable Temperature	=	200°F
Minimum Usable Temperature	=	-40°F
Tack-free Time - 75° to 80°F	=	16 hours

The polyurethane mastic shall be Linabond Mastic.

3. The surface activator shall be a catalytic polyurethane providing crosslinking of the polyurethane mastic with the polyvinyl chloride lining and shall have the following properties:

Solids	=	25%
Color (Gardner)	=	1
Weight/gal	=	9.5 lbs
Surface Dry	=	45 min.
Hardness (sward)	=	@45
Flexibility (1/8")	=	pass
Tensile (ASTM D412) =	>	2,200 psi

The surface activator shall be Linabond CLA-1.

4. Polyvinyl chloride lining material shall be a homogeneous thermoplastic polyvinyl chloride sheet material of 30 mil thickness. The polyvinyl chloride lining shall be white in color.

The PVC test procedures during manufacturing shall be as follows:

a. Randomly select and observe 18"-36" full width sample of material over back lighting of at least 100 watt power. The whole 150 foot role passes over the light box and is subject to review.

b. Record number and size of any voids, if present.

c. Review material according to established acceptance and rejection limits, which currency are as follows: The sample of the product is to be 99.9 percent pinhole free (no more than five pinholes per yard of sample for acceptance of the lot).

Premolded corner units shall be used at all corners and shall conform to the material specification and minimum thickness as stated herein. The maximum thickness allowed shall be 100 mils. The minimum lap with the sheet lining shall be the full 3-inch dimension. PVC premolded corners shall be supplied by Linabond Inc.

Installation shall be as follows:

The Contractor shall provide materials, equipment and labor required to complete the work of applying a protective co-lining to the concrete surfaces indicated on the drawings. The protective co-lining system shall be a flexible membrane that is fastened to the concrete surface with a flexible polyurethane mastic over the entire contact surface. The membrane shall be set into the surface applied mastic while wet and cured to form a protective lining system for the concrete substrate.

Before starting the lining work, the Contractor applying the protective co-lining system shall thoroughly inspect all concrete surfaces to be coated. The Contractor shall repair defective surfaces as directed by the Engineer and as specified herein. The Contractor shall inspect the repaired areas of defective surfaces prior to commencing his work. Commencing of work shall be construed as acceptance of the surfaces and it shall be the responsibility of the Contractor to correct any defect appearing in the surfaces, mastic or lining when work has begun.

Preparation of concrete surfaces for rehabilitation work:

If the surface is for application of the co-lining is to be rehabilitated, the structure surface shall be thoroughly cleaned to produce a clean interior free of all coatings, sand, rock, roots, sludge or other deleterious materials as specified below.

Acceptably cleaned and prepared surfaces shall be free of laitance, efflorescence, oil, grease, rust and other penetrating contaminants. The surface shall be free of fins, projections and loosely adhering concrete and dirt particles. Remove fins and projections by mechanical means.

Concrete substrates with severe hydrogen sulfide damage shall have all contaminated concrete removed by scrabbling, chipping, grinding, brushing, blasting or other methods to a depth where all the white calcium sulfate is removed and only hard grey concrete with a surface pH between 7.0 and 11.0 remains. Any reinforcing steel exposed by removing deteriorated concrete shall be thoroughly cleaned by sandblasting to remove all contaminated concrete and rust particles. Immediately after the cleaned reinforcing steel is inspected and accepted by the Engineer, the Contractor shall place a protective coating on the exposed reinforcing steel using 40 mils of Sikatop 108, Armatec, or 20 mils in two coats of Sika Armatec 110. When the deteriorated concrete is removed, the Contractor shall thoroughly clean the surface to remove all fines and deleterious materials that will adversely affect the bond of the proposed repair material.

Inspection of Concrete Surfaces: All surfaces where deteriorated concrete has been removed will require inspection by the Engineer to determine if the concrete is sound prior to commencement of the repair operation. The surfaces will be tested for acidity and moisture. If the pH of the surface is less than 7.0 additional concrete shall be removed to a depth where the surface reading is equal to or greater than a pH of 7.0. Moisture readings for the surface of the concrete will be performed to verify the specification requirements of the manufacturer of the repair and lining materials.

Repair of Concrete Surfaces for rehabilitation work:

Concrete surfaces which are to receive a protective co-lining system and which have deteriorated to the point where they are not suitable for lining shall be repaired with a polymer cement patching compound or with pneumatically placed concrete (mortar) or with structural concrete repair consisting of pneumatically placed concrete and reinforcing steel. The Contractor shall rebuild the concrete surfaces to their original lines and shapes where damaged concrete has been removed as stated above.

All concrete surfaces that are repaired and which are to receive a protective co-lining system shall have a controlled pattern sweep of sandblast or waterblast to remove all laitance from the repaired areas. The blast pattern shall be by systematic removal from a defined rectangular area. The blasting operation shall be followed by a thorough cleanup operation including air drying and vacuuming to provide a clean dry surface for the protective co-lining system.

Polymer Cement Patching Compound: A polymer cement patching compound by Sika Corporation, Sikatop 123 or 122; Master Builders, Masterpatch 210 or 230 VP, or equal, shall be used to repair the deteriorated concrete surfaces. The patching compound must be accepted by the protective co-lining manufacturer and the Engineer as to compatibility with the protective co-lining. The Contractor shall follow the instructions and recommendations of the patching compound manufacturer as to application, giving special attention to their time requirements, depth of repair, surface preparation procedures and curing time.

Pneumatically Placed Concrete: Pneumatically placed concrete conforming to Department specifications, may be used as an alternative method of repairing the deteriorated concrete surfaces where surface areas are extensive and have depressions greater than 1/2 inch. The minimum compression strength shall be 4,000 psi after 28 days, and shall be water cured for a minimum fourteen (14) days before any application of the protective co-lining system can proceed.

Structural concrete repair shall be used to repair deteriorated concrete surfaces with fill depths greater that 2 inches that have the existing reinforcing corroded away and at areas as may be required by the Engineer. The areas shall be repaired using pneumatically placed concrete as specified above along with reinforcing steel as needed. Existing reinforcing steel that remains and is exposed shall be coated with 40 mils of Sikatop 108, Armatec, or 20 mils in two coats of Sika Armatec 110.

All surfaces where structural concrete repair materials will bond with existing concrete shall be coated with the bonding agent Sika Armatec 110, by Sika Corporation. The bonding agent shall be applied in strict accordance with the manufacturers instruction and shall have a minimum thickness of 20 mils.

Finish of Repaired Surfaces:

General: The repaired concrete surface shall in general have a finish that will match the uncorroded surface.

Surface Finish: "Ordinary Surface Finish" shall approximate the required finish for the protective co-lining system.

Procedure for Finishing: The final finish shall be flat and smooth by wood float or steel troweling. The concrete repair material manufacturer's requirements as to finishing shall be strictly adhered to, as particularly as to time and moisture requirements

Curing of repaired concrete with Polymer Cement Patching compound shall be in accordance with manufacturer's instructions. Curing of pneumatically placed concrete shall be by continuous water sprinkled cure for 14 days (i.e., 10 days wet cure and 4 days of drying time). Concrete curing compounds are not allowed. The Contractor shall protect the newly repaired concrete from freezing temperatures and scarring or other damage.

The Contractor shall measure the surface pH, moisture content and temperature of the prepared concrete surface prior to beginning the lining operation. The acceptable ranges, as recommended by the lining manufacturer, shall be used to determine whether lining application may proceed and shall determine the choice of primer to be applied. The Contractor shall also check the concrete surfaces for residual laitance by visual inspection with magnification if necessary and by primer application on suspect areas. If the primer does not penetrate the concrete surface by turning the surface dark and the laitance area can be visually detected; the Contractor shall not accept the surface and shall have the area sandblasted or waterblasted again for laitance removal as previously specified.

Installation:

The Contractor shall be responsible for obtaining the services of a qualified and authorized representative of the manufacturer of the protective co-lining system to continuously supervise and provide field instruction and direction to the Contractor during all the protective coating application to insure that the work, including but not limited to, the surface preparation, mixing, drying times and application procedures are performed per the manufacturer's recommendations.

Prior to beginning the lining work, the Contractor shall prepare an area as designated by the Engineer and shall demonstrate the protective co-lining system application. This test area shall be a minimum of 10 square feet and will be used by the co-lining manufacturer and the Engineer for approval of proper application procedures for the lining work. The test application shall utilize the specified primer and shall be applied to both concrete and specified patch material surfaces. The lining in this test area, after three (3) days of curing, must pass inspection and testing as specified below in this Section, prior to Contractor being given written instructions to start the protective co-lining system work.

The protective co-lining shall completely seal the areas shown on the drawings. Application should take place in a controlled environment with a minimum temperature of 65°F.

The epoxy/urethane primer shall be applied to the prepared concrete surface, at a rate not exceed 300 square feet per gallon of primer. The primer shall be allowed to cure to tack before the mastic is applied. However, application of the primer shall precede the mastic application by no more than a 1-hour time period.

The polyurethane mastic shall be applied by troweling at a rate of 4 gallons per 100 square feet with a minimum film thickness of 120 mils. The application of mastic shall not exceed that area which can be lined within 3 hours of application or by the end of the daily work period.

The surface activator shall be applied to the polyvinyl chloride liner material and allowed to tack prior to application to the substrate. Activated polyvinyl chloride sheets shall be protected from debris contamination prior to installation. The top surface of any sheet which will be lapped during installation shall be activated after the sheet is in place.

The polyvinyl chloride liner shall be applied while the wetting ability of the mastic is at its optimum. Care shall be taken to keep the mastic surface and the activated polyvinyl chloride surface clean and free of dust and debris until the lining is set in the mastic. The polyvinyl chloride liner shall provide a complete seal of all the concrete surfaces as shown on the drawings. The Contractor shall utilize the maximum size (not to exceed 8 feet in any direction) liner sheet possible at any application with a minimum of seams. The vertical seams shall have liner material overlapped by a minimum of 4 inches and shall be fully bonded in the mastic to the adjoining sheet. Horizontal seams shall have lining material overlap in the lining sheet below by 4-inches. The edges of the lining shall be thoroughly sealed with the polyurethane where they join existing metal and equipment parts and at top edges. Premolded corners shall be used at all interior and exterior corners and shall be fully lapped (3-inches) with the lining sheets.

All surfaces of the polyvinyl chloride liner shall be thoroughly rolled to remove air inclusions and to ensure the best possible adhesion to the polyurethane mastic. The rolling process must occur immediately after the liner application.

All penetrations of the polyvinyl chloride liner shall be sealed with the polyurethane mastic as shown on the drawings.

The average dry film thickness of the cured protective co-lining system shall not be less than 150 mils.

Curing of Co-Lining:

The finished lining shall be protected from damage during curing and shall be cured as recommended by the co-lining manufacturer but in all cases no less than seven (7) days of curing time shall elapse before the lined area can be returned to service.

Records for Rehabilitative Operations:

The Contractor shall maintain an accurate written record of the amount of each material used for the protective co-lining system that is delivered to the job each day, and the amount used in the co-lining system each day. He shall furnish a signed copy of said record, along with the amount (square feet) of protective co-lining system installed each day, to the Engineer at the end of each working day.

Testing and Inspection:

Upon completion of the installation of the protective co-lining system, the surface of the liner or coating shall be cleaned and prepared to permit visual inspection and adhesion testing by the Engineer.

All surfaces of the liner shall be visually inspected for areas showing poor adhesion, air inclusion, edges or seam defects or any other defects in the lining preventing a complete seal of the protected surfaces.

To assure proper adhesion of the polyvinyl chloride lining to the polyurethane mastic and the mastic to the concrete surface, the protective co-lining system shall have a "peel test" performed at locations previously designated by the Engineer and prepared by the Contractor. The test shall be the "Standard Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants" per ASTM Designation C794-80 and modified for field test conditions. Preparation of the 1-inch wide pulling strips, during the Contractor's lining installation, shall be as directed by the Engineer. The allowable minimum value for the peel strength test shall be per the protective co-lining system manufacturer's recommendation but shall not be less than 16 pounds per linear inch after seven (7) days of curing at a minimum ambient temperature of at least 55°F (ASTM Standard). The areas where the destructive testing (adhesion test) was performed shall be repaired as specified below.

Repair of Defects:

The Contractor shall repair all defects, pinholes, and holidays in the protective co-lining system:

Holidays or pinholes found in the liner and other surface defects which prevent a complete seal of the concrete surface shall be repaired by injection of polyurethane mastic into and around the defect in the liner, followed by an application of new polyvinyl chloride liner.

Small areas of lining that show air inclusion, as determined by the Engineer, shall be penetrated and filled with the polyurethane mastic and relined with a new application of polyvinyl chloride liner over the defect or opening in the lining.

Areas where the liner adhesive strength failed to meet the minimum peel strength testing value as specified above and areas that have air inclusions larger than 4 inches in either direction, shall have all the defective lining, including mastic removed as directed by the Engineer. The area shall be relined with a new application of protective co-lining system, overlapping the adjacent lined areas a minimum of 6 inches in all directions and shall be reinspected to the standards specified above.

Submittals:

The Contractor shall submit the following information regarding the protective co-lining system:

1. Complete description of all the other materials to be used for the installation of the protective co-lining system including written instructions for application (the co-lining system submittal will be by the system manufacturer).

2. Laboratory test data for protective co-lining materials including material safety data sheets (by the system manufacturer).

3. Applicators certification (By the Contractor).

Coating System:

Coating systems are numerous and of varied effectiveness. Some of the products which have been utilized by the Department are listed below. Other products have also been used and new products are constantly becoming available. Some of these products are acceptable while others, when tested are found to have problems in our system. Further, any coating system is highly dependant upon the applicator. One good source of coating information is the "Redner Report"[5]. At present evaluation both by the Department and by the combined consultant and Department "New Technology Evaluation Committee" is on going. It is suggested that the design professional check with the department's Structural Design Unit, Engineering Division, during the design phase for any current information available on a particular system.

CORROSION PROTECTION

1. Kop-Coat Bitumastic No. 300M; 2 coats at a 10-mil per coat dry film thickness of this epoxy paint is frequently specified for use in coating the interior or a wet well or manhole where no particularly severe conditions are anticipated. Not recommended for severe exposures.

2. Sauereisen Coating System; for build up of damaged surfaces utilize F-120 followed by a coating of No. 210. The Sauereisen system has been used by the Department in severe exposures without failure as far as the author is aware.

3. PPC Coatings, PC-Prime Coat, IC-Q Lining Coat, and FC-Final Coat System. This system was originally known as Quantum Coatings and has been utilized by the Department in severe exposures without failure to the author's knowledge.

4. Ceramic Epoxy, Polyurethane and Polyethylene are used in contact with ductile iron pipe by the Department, but are not utilized on concrete. Of these three materials Ceramic Epoxy and Polyethylene are accepted by the Department as interior sewage pipe lining materials. Polyurethane has only been utilized as a exterior coating.

FORCE MAIN DESIGN

Design Considerations

A force main carrying untreated sewage is always considered to be an anaerobic situation and is always to be protected from corrosive attack. Certain plant mains carrying treated effluent, such as outfall lines, do not need full protective measures since their contents are not gas producing.

A primary consideration in the design of a force main is gradients. Many times in the crowded underground conditions of this area gradient changes are required to avoid conflict with other utilities. Each of these changes presents low and high points where gas can accumulate. Each of these points must be dealt with by either venting or sloping the main to another higher point where a vent is located. Gas accumulation due to gradient changes cannot be allowed since it will possibly form a pocket with the potential of restricting flow and/or corroding the pipe surface.

Another gradient consideration is that shallow slopes or horizontal pipelines are a built in problem. When installed in the field, this type of configuration will probably have points which are slightly "humped" above other portions of the line. Such a point can form a small pocket for gas and be a corrosion source.

The author remembers reviewing the TV logs of the initial 54-

inch force main failure in the western area of the county. There was no real high point but rather a slightly higher area in a nearly horizontal run. A small area at the crown of the main had formed a gas pocket and looked almost as if it had been saw cut and the concrete removed approximately six to eight inches wide parallel to the flow axis.

To prevent this type of occurrence, the main should have a slope that is appreciable and further, field installable, without such minor highs forming a gas pocket.

Venting of any high point is absolutely necessary and these vent points must be shown on the plans for concrete mains which must be factory tapped for the outlet. If a main is, after design, changed from ductile iron (which plans do not usually show venting since they are field tapped) to concrete; the engineer doing the concrete piping take off must call for tapped concrete pipe lengths at high point locations.

The Department does not utilize automatic vents on sanitary force mains. This is due to the greater simplicity and higher reliability of the simple hand-operated vent valve system. The public nuisance which can be created by a jammed open vent valve has always been considered as unacceptable.

The force main can always be considered as in a turbulent condition. However, all areas where the force main empties into another force main, a wet well or gravity manhole should also be carefully reviewed to provide a high level of corrosion protection. The same rule applies to chimney or saddle type manholes with bolted down covers located on a pressure main. This situation forms a nearly ideal situation to gas corrosion to take place. Such situations are unusual but in a few instances this type of unit must be installed to permit future access. It should be avoided wherever possible and the standard flush-with-the-pipe manhole used.

Consideration should also be given to the extent of liner coverage necessary in concrete pipes. The Department standard in recent years has become to cover the top 120 degrees of the pipe with "T-Lock". Some older force mains received only 90-degree coverage. The design professional should look at whether the pipe will in all or for part of it's length be exposed to partially full conditions such as at a point where the main is emptying into a wet well or gravity system. If such a condition exists, the area thus exposed may require 180 or 270 degree or greater lining coverage.

From approximately 1992 to 1995 we were ordering all fittings to be 360-degree lined. This practice of 360-degree lining for fittings has recently been stopped. The Department has experienced some lining failures at fittings and it is thought that a contributing cause is the exposed upstream-facing edge of a 360-degree lined fitting at the point of connection to a 120-degree lined straight length of pipe.

Another point of consideration is the external exposure of the main to a "hot soil" , ie a highly conductive or otherwise corrosive soil condition. This is not too common in our area. However, pipeline runs through fill areas, areas where vegetation is present or buried in the soil, saturated alkaline soils or old dump areas should be regarded with suspicion. Test procedures for corrosive soil conditions is included in ANSI/AWWA C105.[6]

A common external corrosion situation in our area is burial of the pipeline in areas of salt or brackish ground waters. These can occur surprisingly far inland if near a creek or waterway.

Due to this condition being common in our area the Department prefers to have all ductile iron pipe main contracts specified with an item for the cost of polyethylene encasement per ANSI/AWWA C105 included in the proposal. The cost of this work is included as a contingent bid item which is deleted if found to be unnecessary.

Concrete mains have not, in general, been encased in polyethylene due to the cost and difficulty in practice of performing such an encasement of the sizes of pipe commonly using concrete as a material. Furthermore, the author is unaware of any problems experienced with external corrosion failure or attack of concrete mains.

The author does know of one concrete main that was protected against external corrosion in an FP&L easement. This was accomplished by bridging the pipe joints to form one long conductive run and placing a sacrificial zinc anode system in electric bond with the pipe. This design work was performed by a consultant specializing in this type of exercise and should be left to someone well acquainted with this field of expertise if such a requirement surfaces.

<u>Force Main Materials</u>

Cast, Ductile Iron:

This is the most common material of use for Department force mains. It is always in sizes of 8-inch and larger lined with either polyethylene or ceramic epoxy for 360 degree coverage of the pipe interior. Detailed specifications for both pipe and coatings are included elsewhere external to the corrosion report and will not be repeated herein. Pipe below 8-inch diameter (which is not available lined with these materials) is either unlined or cement mortar lined.

Concrete: This material is the second most common force main material and is now always lined with a "T-Lock" liner in the upper areas of the pipe as previously discussed. Specifications for both pipe and liner are included elsewhere external to the corrosion report and will not be repeated herein.

Fiberglass:

This material is divide into to major categories: RTRP, Reinforced Thermosetting Resin Pipe, and RPMP, Reinforced Plastic Mortar Pipe.

RTRP, is a filament wound, glass fiber and resin construction formed on the exterior of a mandril. Most commonly these days it is restricted to smaller diameters since it usually cannot be competitive on a cost basis with RPMP. This type of pipe has excellent corrosion resistance for normal non-industrial sewage and has been successfully used by the Department. It will also withstand longitudinal thrust loads caused by pipe pressure. To the author's knowledge, no force mains have been constructed for the Department utilizing this material in a direct bury configuration mainly due to ductile iron and concrete cylinder pipe being the preferred and most cost effective materials.

Basic specifications and design calculations are covered in ANSI/AWWA C950.[7]

RPMP, is a chopped glass fiber reinforced thermosetting resin pipe with a sand filler, the most commonly encountered form found in this area being by Hobas Pipe. This pipe is commonly used in larger diameter constructions and is fabricated by spraying the material into the interior of a rapidly rotating external form. This pipe has been utilized by the Department in the rehabilitation of large calibre sewer interceptors on numerous occasions. It has excellent structural characteristics and is highly corrosion resistant. However, it has not been used in direct bury situations mainly due to cost and the fact that it cannot withstand thrust stresses caused by pressure applications. This results in no thrust resistive joints being available and thus all is dependent upon thrust blocking. This does not comply with Department standards and prevents use of the material in pressure applications.

CORROSION PROTECTION

High Density Polyethylene:

This material, HDPE, is a thick smooth walled pressure construction supplied by such firms as Drisco Pipe (Phillips Petroleum) and Sclair Pipe out of Canada. It is generally heat welded by a special machine into long lengths and then pulled through an existing sewer pipe by cable for rehabilitative work. The Department has used it in this type of activity an has had excellent results. Economically it is viable generally in smaller calibers with fiberglass being more appropriate in sizes above 42-inch diameter. To date the Department has not used this material in direct bury instances for force main work due to ductile iron and concrete cylinder pipe being considered more desirable for this application. However, it is being considered for use in a directional drilling application currently under design which will result in a direct bury situation with the flexability of this construction being desirable for this type of installation technique. The material has good pressure and corrosion resistance. Basic product specifications and standards are covered in AWWA C906[8] and basic design calculations are available in the Driscopipe manual.[9]

Polyvinylchloride:

PVC is frequently used by the Department in non-pressure applications and in small calibers for pressure piping of some materials that corrode metallic pipes. The material has not to date been utilized for force main construction since ductile iron is considered more desirable by the Department. This material is specified elsewhere external to the corrosion report and the specifications will not be repeated herein.

Steel, Carbon and Stainless:

Carbon steel is, except for special applications to fuel and air lines, always galvanized. It is specified elsewhere herein external to the corrosion report and those specifications will not be repeated herein. The Department has also used for some digester gas transmission lines in the Central District Wastewater Plant, steel pipe lined with polyproplene.

Stainless steel pipe, as used by the Department, is always Type 316 or 316L. This is due the molybdenum content which allows it to better resist corrosion attack by halides. This has also been found to hold true in practice by the Department.

Type 302, 303 and 304 Austinitic stainless steels have not been found to be as resistant to sewage corrosion in our conditions as 316. However, these steels are the best choice for oxygen piping applications.

Vitrified Clay:

This material is difficult of installation due to the brittle nature of the material. However, nothing could be better for sewage corrosion resistance in a gravity pipeline if properly installed. Specifications are covered elsewhere external to the corrosion report and will not be duplicated herein.

Force Main Coatings and Linings

The ceramic epoxy, polyethylene and Linabond co-lining protective systems are covered under the specifications for ductile iron pipe external to the corrosion report (for the first two) and under the pump station linings in this document for the last. Polyurethane has not been used by the Department as an interior coating except in one instance to the knowledge of the author. It has been specified for use as an exterior protective coating on the ductile iron force main replacement near Pump Station No. 301 near Sunny Isles. This is an unusual situation where the exterior of the existing ductile iron pipe was corroded to failure.

Exterior tape wrap and coating protection is at times used for small caliber steel pipe which is not galvanized due to it's application, such as diesel fuel lines. Basic specifications are given in the AWWA Standards.[10]

Polyethylene wrap corrosion protection of buried pipelines is specified in AWWA Standard C105[11] as previously mentioned.

CORROSION PROTECTION

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2. "Water Environment & Technology", Vol.2 No.7, July 1990, *Hydrogen Sulfide Treatment in Sanitary Sewers*, J.D. Chwirka, T.T. Satchell, Pages 49,50.

3. "Water Environment & Technology", Vol.2 No.7, July 1990, *Case Histories of Sulfide Corrosion: Problems and Treatments*, R.A. Witzgall, I.S. Horner, P.L. Schafer, Page 47.

4. Risk Reduction Engineering Laboratory Office of Research and Development, U.S.E.P.A.; *Improvements in Pump Intake Basin Design*, R.L. Sanks, G.M. Jones, C.E. Sweeney; Pages 13 through 15.

5. County Sanitation Districts of Los Angeles County, Feb., 1994, *Evaluation of Protective Coatings for Concrete*, J.A. Redner, R.P. Hsi, E.J. Esfandi

6. American Water Works Association, ANSI/AWWA C105/A21.5-93, *American National Standard for Polyethylene Encasement for Ductile-Iron Pipe Systems*

7. American Water Works Association, AWWA C950-88, *AWWA Standard for Fiberglass Pressure Pipe*

8. American Water Works Association, ANSI/AWWA C906-90, *AWWA Standard for Polyethylene (PE) Pressure Pipe and Fittings, 4 In. Through 63 In., for Water Distribution*

9. Phillips Driscopipe, Inc., *Driscopipe Systems Design*

10. American Water Works Association, ANSI/AWWA C214-89 and C215-94, *Tape Coating Systems for the Exterior of Steel Water Pipelines* and *Extruded Polyolefin Coatings for the Exterior of Steel Water Pipelines*, respectively.

11. Ibid No. 6